airway. Earlier surgical interventions to relieve the symptoms of postpneumonectomy syndrome were directed at the great vessels that were compressing the airway. Specifically, dividing the aortic arch, bypass grafts, and suspending the aorta from the posterior surface of the sternum were all attempted in an effort to relieve the compression of the airway. These procedures, however, had limited success. In patients who had airway compression from a vertebral body, attempts to remove part of the bone by surgery were also unsuccessful in the long-term management of this syndrome. In the early 1990s, Grillo and colleagues reported good success by repositioning of the mediastinum in patients with this condition. During this procedure, the mediastinum was repositioned in the center of the chest after being freed up from adhesions. To prevent re-shifting of the mediastinum, the postpneumonectomy space was filled with non-absorbable materials. Material such as silicone or saline breast implants, testicular implants, and sulfur hexafluoride have been used. Today, saline-filled expandable breast implants are most frequently employed as they are felt to be the safest, and offer the advantage of easily being made larger if needed. This is of particular importance in the management of growing children with postpneumonectomy syndrome. Patients undergoing surgical re-positioning of the mediastinum with placement of an implant into the pleural space have had resolution of symptoms, and good long-term survival.

Patients with underlying tracheobronchomalacia require an additional procedure after repositioning of the mediastinum, that is, treatment of the airway malacia. Placement of self-expanding metallic stents appears to be the most effective treatment for the tracheobronchomalacia. Resection of the damaged airway or placement of Silastic tubes has been associated with high mortality rates and poor outcomes.

See also: Bronchomalacia and Tracheomalacia. Symptoms of Respiratory Disease: Cough and Other Symptoms.

Further Reading

Subcutaneous Emphysema

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Abstract
Subcutaneous emphysema describes the presence of gas in subcutaneous tissue. It has several known causes, among them anaerobic infections, traumatic disruption of mucosal surfaces, and alveolar rupture. Diagnosis is characterized by the presence of crepitation on palpation over the affected area and radiographic evidence of gas in the subcutaneous tissues. The pathogenesis relates to the tracking of gas along fascial planes into the subcutaneous space of the neck, chest, or extremities. Therapy of subcutaneous emphysema itself is generally supportive and involves the treatment of the underlying condition, as subcutaneous emphysema is usually self-limited and benign. However, the appearance of subcutaneous emphysema often warrants a search for more serious underlying pathology such as pneumothorax, pneumomediastinum, or tracheobronchial or esophageal disruption.

Introduction
Subcutaneous emphysema is a term used to describe the finding of gas within subcutaneous soft tissues, usually in the thorax or neck. The first known description dates back to the seventeenth century, when Louise Bourgeois, midwife to the Queen of France, described crepitations in patients associated with the extreme effort of childbirth. In the nineteenth century, Laennec provided a description in his Treatise on the Diseases of the Chest and Mediate Auscultation. Subcutaneous emphysema is a relatively common clinical finding associated with a broad range of disorders of varying degrees of severity, including trauma, surgery, tube thoracostomy placement, infection, and positive pressure ventilation. One study of 134 consecutive patients with chest tubes found 25 (18.6%) had subcutaneous emphysema. The incidence has not been described in any systematic way, presumably because subcutaneous emphysema is associated with such a diverse range of conditions and is typically a self-limited process of little direct clinical consequence. In general, knowledge of subcutaneous emphysema stems from individual case reports, small series, and clinician experience.
Etiology

Generally, the etiologies of subcutaneous emphysema can be divided into three major categories: infectious, particularly with anaerobic organisms; traumatic, both environmental and iatrogenic (from surgery or other procedures); and so-called spontaneous or pressure related (Table 1). Genetic factors or inherited patient characteristics predisposing to subcutaneous emphysema per se are unknown, although both genetic and environmental factors contribute to some of the underlying potential causes of subcutaneous emphysema, such as congenital pulmonary blebs on the surface of the lung.

Pathology

On gross examination, the presence of subcutaneous emphysema is confirmed by finding gas, usually air, within the subcutaneous tissue. Histologically, vacuolization within the subcutaneous tissue is seen. The presence of air in the subcutaneous tissue can be confirmed by opening tissues underwater. Such techniques have been recommended, for example, when performing autopsies in cases of barotrauma related to scuba diving.

Clinical Features

Patients may complain of puffy face, neck, arms or chest, dyspnea, or awareness of a ‘crackling’ sensation under the skin. The hallmark physical examination sign of subcutaneous emphysema is crepitation on palpation of the affected area. It should not be painful. When associated with pain or erythema, the presence of subcutaneous emphysema should alert the clinician to the possibility of a serious underlying pathology such as infection. Regions of involvement vary according to the etiology of the subcutaneous emphysema. The site where the gas is first noted may help to identify the site of origin: air in the neck suggests antecedent pneumomediastinum or a rupture of the esophagus as the site of injury, whereas air in the flank or abdominal wall suggests the retroperitoneum as the site of origin. Air may be seen initially near a rib in the case of rib fracture.

The most frequently affected sites include the subcutaneous skin overlying the neck and thorax. There is often overlap in areas of involvement due to anatomic considerations (see following section on pathogenesis). There may be marked distension of the skin due to entrained air, such that patients may be grossly disfigured. For example, subcutaneous emphysema involving the eyelids can become so severe as to cause the eyes to be completely shut. Air dissecting to the soft tissues of the larynx can produce hoarseness or a so-called hot potato voice. Gas in the retropharyngeal area may also give a nasal quality to the voice. Although fever and leukocytosis have been reported in isolated subcutaneous emphysema, such findings should raise suspicion for infection.

Subcutaneous emphysema is frequently associated with pneumomediastinum, which is accompanied by stabbing precordial chest pain in as many as 80–90% of affected individuals. On examination of the anterior chest, the so-called Hamman’s crunch is reported in 50–80% of patients. This auscultatory finding consists of a crackling sound in the retrosternal location synchronous with the heartbeat.

Radiographically, subcutaneous emphysema is appreciated as pockets of gas density within subcutaneous regions. This air frequently outlines anatomic
structures such as the fascial planes of the chest and neck, the axilla, and the pectoralis muscles (Figures 1 and 2). The presence of subcutaneous emphysema on a chest radiograph should prompt a careful radiographic search for pneumothorax, pneumomediastinum, pneumoperitoneum, or fractures. Occasionally, the presence of pneumomediastinum is uniquely evident on a lateral chest radiograph.

Appropriate investigations for subcutaneous emphysema depend upon the clinical scenario. When infection is suspected, blood cultures and pertinent imaging should be initiated. Careful examination of the oral cavity, the source of many such infections, is mandatory. In cases of trauma, concern centers on the potential disruption of mucosal surfaces within one or more segments of the airways: nasal mucosa and paranasal sinuses; retropharynx and larynx; trachea and lower airways; or esophagus and lower gastrointestinal tract. Appropriate imaging may include X-rays or computed tomography (CT) scans of the chest or neck. When airways disruption is suspected, immediate bronchoscopy is warranted to evaluate for tracheobronchial rupture. Intraoperative bronchoscopy under general anesthesia may be advantageous, since bronchoscopy in an uncontrolled setting has the potential to worsen airway damage and compromise the airways. Intraoperative visualization allows for surgical correction immediately following diagnosis. Upper GI endoscopy is indicated if esophageal rupture is suspected as, for example, in Boerhaave’s syndrome.

Pathogenesis

The respiratory and gastrointestinal tracts are closed systems surrounded by subcutaneous, prevertebral, visceral, and previsceral spaces (Figure 3). Air arising from a breach in the mucosal integrity of the respiratory or gastrointestinal tract can enter the visceral space and dissect along facial planes into the subcutaneous space, creating subcutaneous emphysema. Traumatic causes of subcutaneous emphysema are numerous. Blunt or penetrating trauma to the neck or chest can result in disruption of the tracheobronchial tree and tracking of air along fascial planes into the subcutaneous space. More than 80% of such injuries occur within 2–3 cm of the carina. Similarly, esophageal rupture can lead to subcutaneous emphysema as a result of penetrating trauma or from increased intrathoracic pressure as with protracted, severe vomiting. Iatrogenic causes of subcutaneous emphysema are not uncommon. Examples include dental procedures such as extractions or drilling of lower molar teeth. A number of case reports describe traumatic endotracheal intubation as a causative factor, particularly with the use of a rigid stylette extending beyond the tip of the endotracheal tube. Tracheobronchial rupture has also been reported during diagnostic bronchoscopy. Subcutaneous emphysema occurs frequently following tube thoracostomy placement, particularly in the setting...
of: antecedent trauma; the presence of a broncho-pleural fistula; the presence of large, bilateral pneumothoraces; the placement of chest tube outside of the operating room; or mechanical ventilation.

More distally, air can be introduced into the subcutaneous space at the alveolar level in a nontraumatic fashion by alveolar disruption. This process requires a pressure gradient between the alveolar space and the lung interstitium. With alveolar rupture, air tracks along bronchovascular bundles within the bronchovascular sheaths, reaching the mediastinum through the visceral space, resulting in pneumomediastinum. Subsequently, free air can dissect into the subcutaneous and retroperitoneal spaces, cervical soft tissue, or decompress into the pleural space, resulting in a pneumothorax. Most commonly, this form of nontraumatic subcutaneous emphysema results from positive pressure mechanical ventilation. Other etiologies include obstructed air flow during asthma exacerbations, viral-induced bronchiolitis in children, mechanical upper airways obstruction due to tumor or foreign body, or decompression sickness. Decompression sickness in scuba divers is the result of rapid ascent. As the pressure is

Figure 3  Soft-tissue compartments of the neck (level of C-7), thorax (levels of T-2 and T-5), and abdomen (level of L-1), demonstrating the continuity of the visceral space between regions and the adjacent nature of the subcutaneous space. Reproduced from Maunder RJ, Pierson DJ, and Hudson LD Subcutaneous and mediastinal emphysema: pathophysiology, diagnosis, and management. Archives of Internal Medicine, 1984, 144: 1447–1453, with permission. Copyrighted © (1984), American Medical Association, All rights reserved.
rapidly decreased, the volume of gas in the lungs increases, causing gas to escape into the bronchoesophageal sheath and dissect its way into the subcutaneous tissue. More serious problems from decompression sickness include pneumothorax and air embolism.

In necrotizing infections, gas is produced within the subcutaneous tissue by anaerobic organisms. Subsequent dissection along facial planes can occur as outlined above. These infections tend to occur in tissues that are in proximity to mucosal surfaces covered by anaerobic bacteria or within tissue that has been damaged long enough to allow necrosis to develop. A broad range of bacterial species are capable of producing gas in subcutaneous tissue, including: anaerobes such as *Clostridium, Bacteroides*, peptostreptococci; and facultative anaerobes, such as *Escherichia coli* and *Klebsiella* species.

**Management and Current Therapy**

In the vast majority of cases, the management of subcutaneous emphysema is supportive, since the problem is generally self-limiting. Of primary importance is treatment of the underlying condition. When subcutaneous emphysema has developed from barotrauma during mechanical ventilation, weaning and liberation from mechanical ventilation should be performed, if possible. If not clinically possible, attempts to favorably modify lung mechanics so as to decrease mean airway pressure should be performed. As clinically warranted, such measures may include the administration of bronchodilators, decreasing inspiratory time (by decreasing tidal volume and/or increasing the flow rate), and decreasing the amount of positive end expiratory pressure. Suspected infections should be treated aggressively with appropriate antimicrobials and, if indicated, surgical debridement. Traumatic sources of subcutaneous air should be sought and managed surgically, as warranted. Tracheobronchial disruptions generally require operative repair.

Tube thoracostomy is warranted for pneumothorax, particularly if the patient is receiving mechanical ventilation. However, empiric insertion of a chest tube for subcutaneous emphysema is without clear benefit, and is not recommended unless a pneumothorax is also present. Other procedures that have been attempted include infraclavicular skin incisions, tracheostomy, and subcutaneous drains with or without suction. Such procedures have not been well studied, may be associated with complications such as infection, and are not recommended for the routine management of patients with subcutaneous emphysema, even if receiving mechanical ventilation.

Subcutaneous emphysema is usually a self-limiting, cosmetic problem. However, when severe, it can result in significant tissue distortion and problems such as transient vision loss or dysphagia. It can also be a nursing problem, leading to difficulty in gaining intravenous access or caring for wounds. Rarely, severe complications have been reported from subcutaneous emphysema: airway compromise, respiratory failure, pacemaker malfunction, or cardiac tamponade physiology (in conjunction with pneumomediastinum). When associated with chest tube placement, the presence of subcutaneous emphysema is linked with an increased length of stay in the hospital and increased mortality compared to patients with chest tubes who did not develop subcutaneous emphysema.

**Further Reading**


Macklin CC (1939) Transport of air along sheaths of pulmonic blood vessels from alveoli to mediastinum: clinical implications. *Archives of Internal Medicine* 64: 913–926.

